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Development of the Breakaway Integrated Chin-Nape Strap

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Development of the Breakaway Integrated Chin Nape Strap (BICNS)

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Abstract

Helmet-mounted systems (HMS), such as night vision goggles and helmet-mounted displays, are designed to enhance pilot performance through improvements in situational awareness, target acquisition, and weapon delivery. Using HMS, however, may also affect pilot safety by increasing the potential for neck injury during ejection due to the increase in dynamic forces generated in the cervical spine as a result of the change in helmet inertial properties. The majority of these increased forces occur during the windblast and catapult phase of the ejection. Smaller crewmembers and those who eject with poor positioning are especially at risk. Previously, helmets were equipped with a chin-strap that would allow the helmet to separate from the crewmember during an ejection. However, new strap systems have been designed to stabilize the helmet and improve helmet retention so that HMS can be properly used. This stabilization system has demonstrated a higher probability of a neck injury occurring during an ejection. To balance the issues of helmet stability with helmet retention and neck injury, a new chin-strap system has been developed. This system has been demonstrated through laboratory and in-house testing to be a promising solution.

Background

The decision on whether or not to eject from an aircraft is always a last ditch effort after a pilot has exhausted all other methods to recover. A typical ejection can be thought of as a complex connection of dynamic events. The crewmember is first exposed to a compressive load during the catapult phase as the seat is forced from the cockpit of the aircraft. As the seat begins to emerge, the crewmember is exposed to a windblast. This blast effect dramatically increases with the airspeed, with 450 KEAS commonly used as the delineating phase between low-speed and high-speed ejections. After the seat has fully cleared the cockpit, two stabilizing drogue parachutes are deployed to slow the seat during a high-speed ejection. After the seat has been slowed, the crewmember is separated from the seat and the main parachute opens, imparting high forces to the crewmember. The entire sequence finally ends when the crewmember lands on the ground. During all phases of the ejection sequence, there is a potential of injury from the large dynamic forces.

✓ The windblast can impart a large tensile load to the crewmember's neck by creating lifting forces on both the head and the helmet (Figure 1). In some cases, the lifting loads on the helmet can be so great that the helmet is actually removed from crewmember. Previous helmet systems such as the Separate Chin Nape Strap (SCNS) would typically

release the helmet (Figure 2) when large tensile forces were applied, such as those experienced during high-speed ejections in the windblast phase (Pellettiere 2003).



Figure 1. Manikin in the ejection seat up the rails

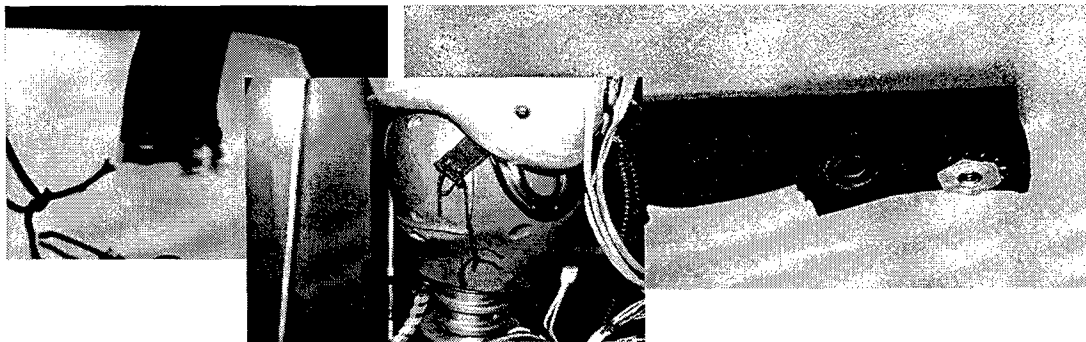


Figure 2. Helmet Release after nape and chin-strap failures of the SCNS

Recently, the use of Helmet Mounted Systems (HMS) such as Night Vision Goggles (NVG) or Helmet Mounted Targeting/Displays (HMT/D) has increased. These systems have stricter requirements regarding stability of the helmet on the head. These requirements are driven by the need to have a constant location of the optics with respect to the exit pupil location of the particular crewmember. To improve the helmet stability, a new strap was developed, the Integrated Chin-Nape Strap (ICNS). The ICNS has demonstrated an improvement of the helmet stability and also that of helmet retention during an ejection. This change to the strap and the inclusion of HMS has also led to the increased potential of large tensile neck loads (Figure 3). In addition, it was determined that the helmet shell itself would fail before the ICNS ever did (Figure 4).

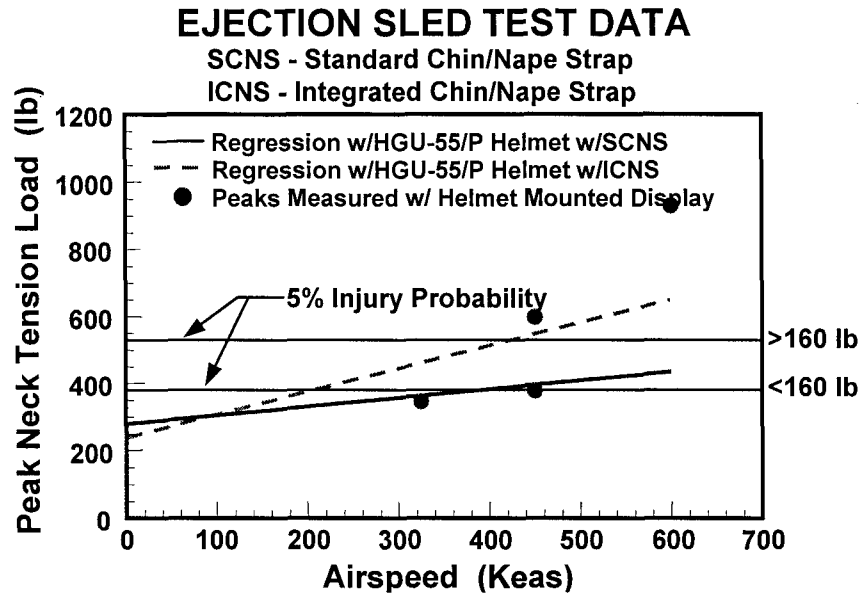


Figure 3. Neck tensile loads as a function of airspeed

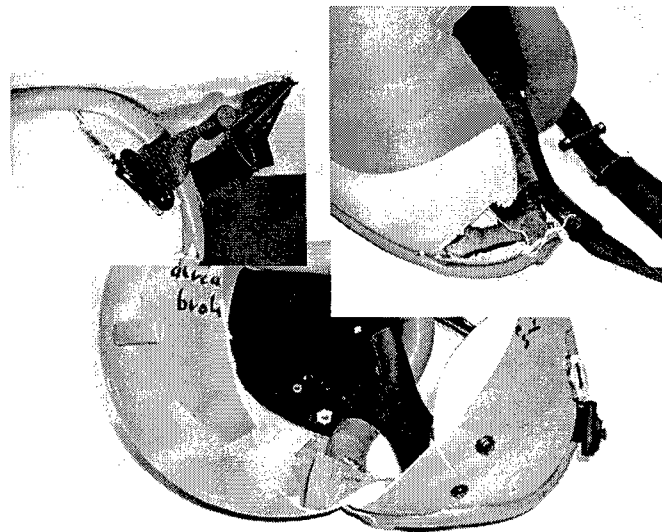


Figure 4. ICNS helmet shell failures

Concurrent with the increased use of HMS, the anthropometry of the aircrew has been expanding to include smaller and larger sized individuals as well as a greater proportion of females. Concerns have arisen that females and smaller-sized individuals may have a greater risk of a tensile neck injury during an ejection. This concern is based upon the differing neck strength of different-sized individuals. To determine injury potential, research has been conducted to develop a tensile neck injury criterion (Carter et al. 2000). This criterion allows designers to evaluate the effectiveness and practicality of potential countermeasures and perform a risk assessment.

Because of the concerns of a neck injury during ejection with the ICNS and with smaller individuals, a program was initiated to investigate the possibility of developing a system that could provide relief to the crewmember in the event that large tensile loads would be imparted to the neck through the helmet system. To effect this development, a balance would need to be struck between helmet retention and helmet release. The helmet system provides valuable protection to the head during the ejection event. The helmet bears the brunt of any impacts with the headrest, flying debris, parachute risers, or during the time that the crewmember is impacting the ground after a successful parachute opening and landing. The protective ability of the helmet needs to be retained. However, this protection should not be at the expense of a possible serious or fatal neck injury. If retaining the helmet will allow a life threatening injury to be imparted by the helmet, then it should be released in order to protect the crewmember. For this reason, the Breakaway Chin-Nape Strap (BICNS) was developed to lower the probability of a serious helmet mediated neck injury.

BICNS Design Concepts

The data from the previous system tests of the SCNS (Pellettiere 2002) was used for the basis of developing corridors for a BICNS (Table 1). Two different corridors were developed: one for individuals over 73 kg, who wear a large or extra large sized helmet (L/XL), and one for individuals less than 73 kg, who wear a small or medium sized helmet (S/M). For each size a lower limit was given such that the helmet retention to a specified level could be achieved. If no lower limit was given, then the helmet could release at any level, even if was too soon. The upper level was a tradeoff between neck injury risk and improving helmet retention. Previous testing with the SCNS showed a failure load of approximately 600 Lbs +/- 65 Lbs (Pellettiere 2002). To develop the L/XL corridor, the average failure load for the SCNS was increased by approximately 100 Lbs. The S/M corridor was then taken to be 75% of the large corridor based upon the development of a tensile neck injury risk curve (Carter et al, 2000). It should be noted that these tests include only the helmet and chin-nape strap and not the oxygen mask. Additional testing has coincided to characterize the effects of the oxygen mask (Pellettiere 2004).

Table 1. Tensile neck loading guidelines for helmet systems

BODY MASS	MAXIMUM NECK FORCE	MINIMUM NECK FORCE
For Body Mass Greater than 73 Kg (161 Pounds)	3492 Newtons (785 Pounds)	2891 Newtons (650 Pounds)
For Body Mass Up To 73 Kg (161 Pounds)	2602 Newtons (585 Pounds)	2180 Newtons (490 Pounds)

A solution that would be transparent to the user was one of the primary goals. It was determined that there was very little force exerted on the rear attachment points of the ICNS in comparison to that experienced by the chin strap. The chin strap buckle was therefore a logical place to incorporate the breakaway function (Figure 5). This meant

that no modifications to the helmet would be necessary, other than changing out the current strap.

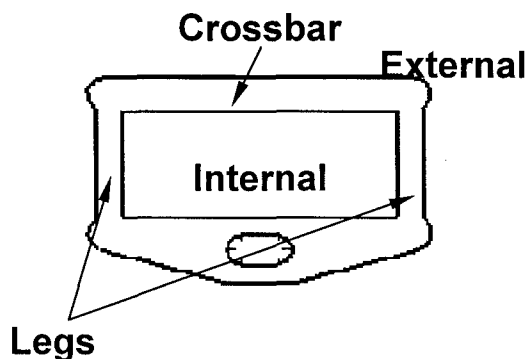


Figure 5. The ICNS buckle

By changing the stainless steel material to aluminum and designing in break points, it was estimated that a controlled separation level could be reached for each of the two breakaway ranges. The stainless steel buckle was too strong to allow for the controlled separation required in each range and yet still maintain user transparency. Therefore an unmodified aluminum buckle was tested in an ICNS equipped helmet which failed prior to helmet failure, supporting the decision to use the aluminum material. The crossbar was thought to be the best place to create the break link in the BICNS and a series of modifications was planned. A number of modifications to the buckle were produced (Figure 6).

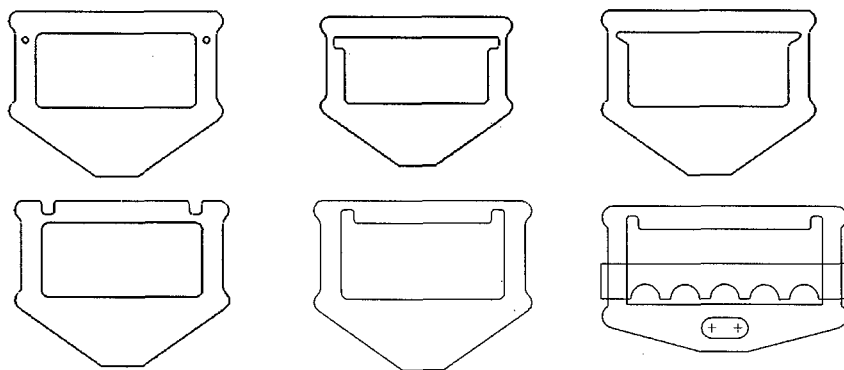


Figure 6. Various BICNS buckle design concepts

Tooling Considerations

The design guideline was to maintain the overall dimensions of the current buckle. The different candidates were analyzed for performance, and those that were deemed acceptable from a tooling design standpoint were fabricated in prototype form and tested. A primary concern with tool design was how tool wear would affect the performance of parts produced over a large quantity. The guideline to maintain the current buckle dimensions was primarily to maintain user transparency. Production tooling exists to

✓ create the stainless steel buckle as a stamped part, and this was used to produce the aluminum "buckle stock" available to try out different notch designs. At the beginning of development, no tooling existed to create all the different notch designs being considered. The notches were machined into this buckle stock. It was recognized that potential differences in performance due to this different fabrication process would have to be accommodated in the future. Soft tools were therefore obtained that would allow final prototype S/M buckles to be completely fabricated by stamping only. One of the soft tool sets is currently being used to fabricate S/M test articles.

The Internal Notch Design

After several iterations of design, a final notch design was selected. Shown in Figure 7 are the chosen designs with the dimensions for the L/XL and the S/M BICNS buckles. This notch demonstrated more consistent breakaway performance than any other design consideration.

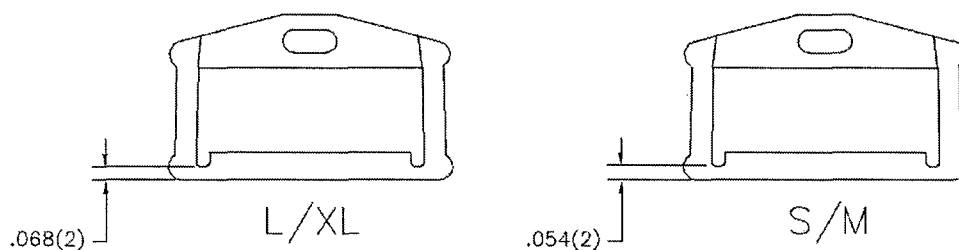


Figure 7. The final BICNS buckle design: an internally notched buckle.

Testing

With this particular design set, several tests were conducted, both at the subsystem level (buckle only) and the system level (installed in the helmet). Other tests included two types of endurance testing, the first was rotational testing to simulate the snapping and unsnapping of a chin-strap, and the second consisted of small load tensile fatigue tests. Windblast testing also took place to simulate a dynamic environment more typical to that experienced during ejection.

Sub-System Level Testing at Gentex

Sub-system level testing was performed at the Gentex in-house facility to measure the performance of the different notched buckle designs. A subassembly of the BICNS, called the strap and buckle assembly (Figure 8), was selected for what has been termed sub-system testing.

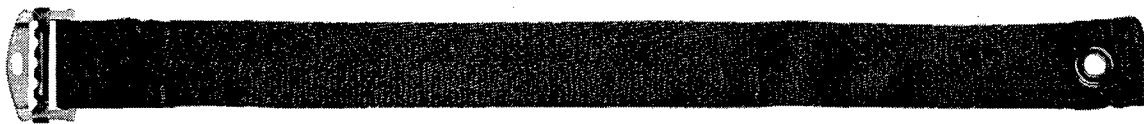


Figure 8. A strap and buckle assembly for sub-system testing.

The sub-system test was performed on an Instron tensile strength tester, located at Gentex Corp. (Figure 9). The sub-system tests utilize the lowest level of subassembly that can be easily tested, with the BICNS buckle in a user configuration, i.e., with the chin strap. The sub-system tests have proved successful in characterizing the performance of both the L/XL and S/M BICNS buckles.



Figure 9. The sub-system test on the Instron textile tensile strength tester.

System Level Testing at AFRL/HEPA

System level tests were performed to determine if the BICNS prototypes fell within acceptable load ranges for the L/XL and S/M straps, as noted above in Table 1. The tests were conducted at AFRL/HEPA, Wright Patterson AFB, on the Material Testing System (MTS) facility. The MTS is a servohydraulic actuator which applies a rapid tensile load to the testing article. The test set-up consisted of a standard 50th percentile Hybrid III neck, a JPATS6 head form (with ears), and a standard HGU-55/P flight helmet. As depicted in Figure 10, a bearing apparatus was used to affix the helmet with the MTS machine, while still allowing expansion and rotation of the helmet. This device also allowed the initial orientation of the helmet with respect to the head to be adjusted. This system imparted only tensile loads to the head/helmet, allowing the helmet to rotate and expand as it would during a windblast or ejection sled test.

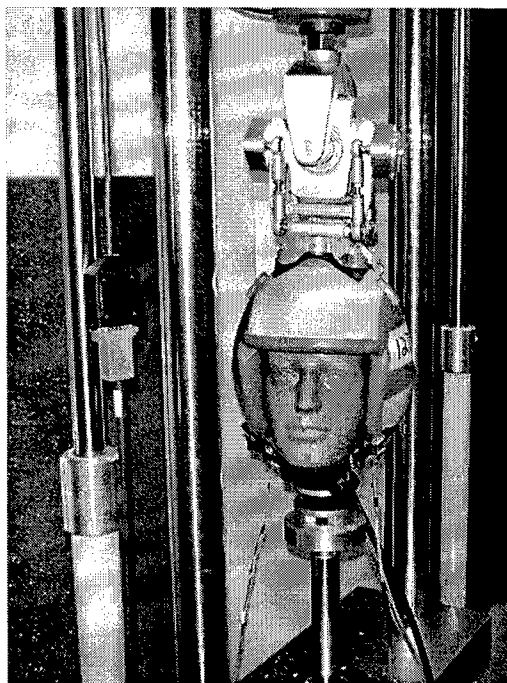


Figure 10. System level test at AFRL/HEPA

Cyclic Fatigue Testing

The everyday action of cinching the chin strap had to be considered in the test program. The section of the crossbar that contains the notches is exposed to forces generated by cinching the chin strap. These forces consist not only of the tension put in place by the cinching but also the rotational force created by the cinching action itself. Tension effects were evaluated on the MTS at AFRL and rotational endurance was evaluated at Gentex. On the MTS, Cyclic tensile tests were run at a 3.5 pound load on two test articles: one to 10,000 cycles and a second test article to 50,000 cycles. The two test articles were then pulled to breakage on the sub-system tester at Gentex. Test article #1 separated at 68 pounds and test article #2 at 65.8 pounds. Since these values were in the same range as un-cycled buckles of the same configuration, it was concluded that no fatigue had occurred.

The rotational test at Gentex consisted of 9,000 cycles, determined through the following algorithm: $4 \text{ cycles/flight} \times 150 \text{ flights/year} \times 15 \text{ years} = 9,000 \text{ cycles}$. The rotational test setup is shown in Figure 11. A cycle consisted of raising the weight by cinching the chin strap and then releasing the weight so it could fall to rest, unloading the chin strap and thus the BICNS buckle. The 10-pound load used in the test represented normal chin strap tensioning multiplied by a factor of three. The tensile and rotational tests were originally run on a notch with only .047" of material remaining. Since all the tests were successful and the current S/M notch design is .054", no repeat testing was contemplated for the final design of the S/M buckle.

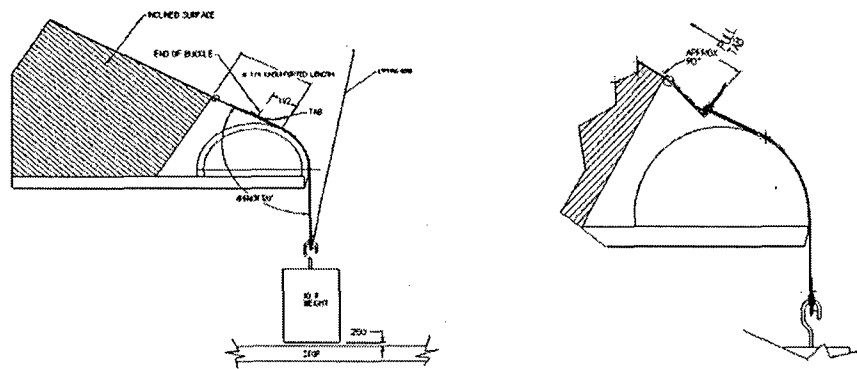


Figure 11. The Gentex rotational endurance test setup.

Windblast Testing

The final BICNS test consisted of windblast testing. The BICNS buckles were installed in helmets that were then fitted to instrumented manikins. Both a large (95th Aerospace) and a small (LOIS) manikin were used for testing. The manikins were dressed in typical flight gear and were seated in ACES II ejection seats. The seat for the LOIS manikin was reclined 34 degrees while the seat for the large manikin was reclined 17 degrees. Several different test configurations were investigated including different airspeeds and visor on or off (Table 2)

Table 2. Windblast test results

Manikin	Seat Angle	Airspeed KEAS	Visor	NFx (Lb)	NFz (Lb)	UNMIx	UNMIz	Comments
LOIS	34*	604	Visor On	39.37	281.37	0.18	0.41	Buckle Retained
LOIS	34*	423	Visor Off	48.15	274.6	0.27	0.48	
LOIS	34*	444	Visor Off	52.83	260.67	0.28	0.28	
95th Aero	17*	603	Visor On	47.53	450.3	0.12	0.2	Buckle Retained
95th Aero	17*	453	Visor Off	36.14	598.69	0.07	0.10	Buckle Retained
95th Aero	17*	603	Visor Off	1.44	435.72	0.14	0.28	Buckle Retained
95th Aero	17*	610	Visor and Mask Off	46.83	218.44	0.13	0.19	
LOIS	34*	351	Visor Off	11.86	133.12	0.15	0.14	Buckle Retained
LOIS	34*	405	Visor Off	41.72	179.55	0.19	0.12	Buckle Retained

Discussion

The final notch dimensions for the L/XL and S/M BICNS buckles were based on performance during sub-system and system level tests. During windblast tests, the L/XL buckle performed as expected. The buckle broke and the helmet separated at 600 KEAS when there was no mask or visor. This would be considered as the worst case scenario for an ejectee. When the airspeed was 450 KEAS or when the visor was retained both at 450 and 600 KEAS, the helmet stayed in place and the neck loads were acceptable. The S/M buckle, however, did not perform as well. The buckle did not break and the helmet did not separate at 600 KEAS when the visor was present, but when the visor was not present the air speed had to be reduced to 400 KEAS to prevent the buckle from breaking. While all the neck loads were within current injury criteria, the S/M BICNS separated too soon and was selected for future redevelopment in order to strengthen and improve its performance.

The fatigue testing, both rotational and cyclic, demonstrated that even with a significant number of loading and unloading, the long term reliability of the BICNS should be high. Only the S/M buckle was selected for fatigue testing since that is the weakest and would be the most susceptible to premature failure. The L/XL performance is expected exceed those of the S/M.

Conclusions

This program successfully demonstrated that a break link can be incorporated into the ICNS to prevent potentially dangerous neck loads. The use of the BICNS should be transparent to the user; however the operational evaluation has not yet occurred. The S/M BICNS is currently being redesigned and those results will be reported at a later date.

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List of Acronyms

AFRL	Air Force Research Laboratory
BICNS	Breakaway Integrated Chin-Nape Strap
HEPA	Biomechanics Branch
HSG	Human Systems Group
ICNS	Integrated Chin-Nape Strap
IPT	Integrated Product Team
MTS	Material Testing System
SCNS	Separate Chin Nape Strap

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Biographies

Joseph Pellettiere is the Technical Advisor and mechanical engineer for the Biomechanics Branch, Human Effectiveness Directorate, Air Force Research Laboratory. He has a BS in Biomedical Engineering and an MS in Mechanical Engineering from Case Western Reserve University, and a Ph.D. in Mechanical Engineering from the University of Virginia. His experience is in biomechanics, human simulation and injury, crash protection and prevention using both testing and computational technologies. He currently leads several projects in the branch including modeling and simulation, seat system interfaces and neck injury protection.

Erica Doczy is a biomedical engineer for the Biomechanics Branch, Human Effectiveness Directorate, Air Force Research Laboratory. She has a BS in Biomedical Engineering from Wright State University and is currently pursuing an MS in Biomedical Engineering. Her experience is in impact biomechanics and human systems test and evaluation. She is currently the associate investigator of a study examining the effects of helmet weight during vertical impacts using manikin and human volunteer subjects.

George Hedges received his Bachelor of Mechanical Engineering degree from the University of Minnesota. His entire career has been devoted to the development and production of products related to human performance and interface with military and space hardware. His initial assignments at the Honeywell Avionics Division in Minneapolis were in the development of cockpit instruments. He moved into the manual controls and displays arena on the Apollo program and then to helmet mounted sights and displays for the Navy (VTAS), the Army (IHADSS), and the Air Force (Magnetic Helmet Sight). Having become acquainted with helmet manufacturing, he moved to Gentex Corporation in Carbondale, PA in 1981 where he worked in engineering management until 2003 when he returned to the technical arena. He is currently a Senior Technical Advisor to the Vice President and General Manager of Helmet Systems.

Charles Acker is a Project Engineer for the Gentex Corporation Helmet Systems business group. His involvement within the business group benefits from his past 18 years experience with protective helmet equipment design, integration, and manufacture for both rotary and fixed wing helmet applications. He received a Bachelor of Mechanical Engineering from the State University of New York Institute of Technology. He holds two patents and is listed as a co-inventor on a third where a patent is pending.